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G1U
G5R
H1K
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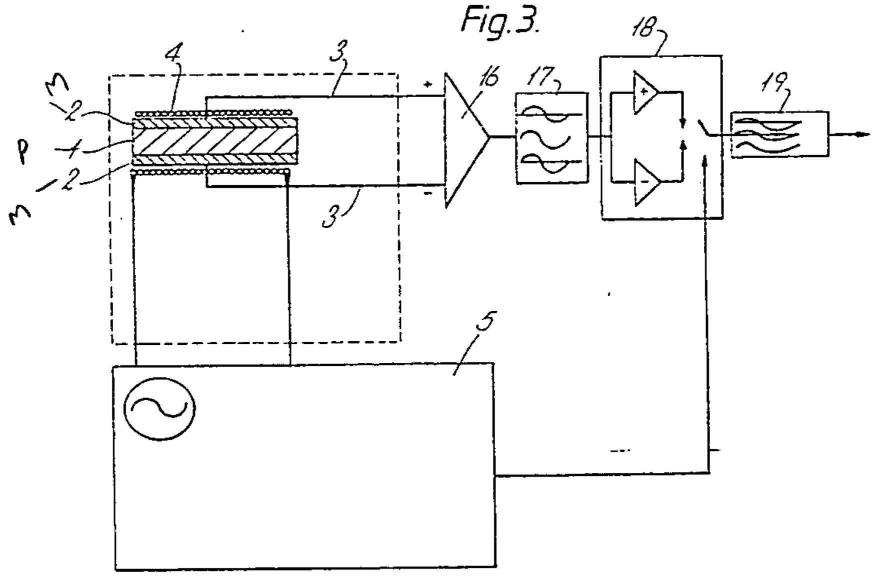
(54) Magnetic sensor arrangements

(57) A magnetic sensor arrangement of the kind wherein an output representative of an applied magnetic field is produced by a piezoelectric member (1) secured to a magnetostrictive member (2) placed in the magnetic field includes an electromagnet (4) for applying an alternating magnetic field to the sensor, and a synchronous demodulator (18) for detecting the amplitude and phase of the alternating component of the output of the magnetic sensor. The arrangement overcomes the effects of surface charge build-up, thermal expansion and electron drift in the sensor. In a modification a further electromagnet coupled to the output of demodulator 18 is arranged so as to apply a d.c. magnetic field to the sensor having a magnitude dependant upon the applied magnetic field but in opposition thereto to provide a negative feedback arrangement.

Fig. 3.



The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

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Fig.1.

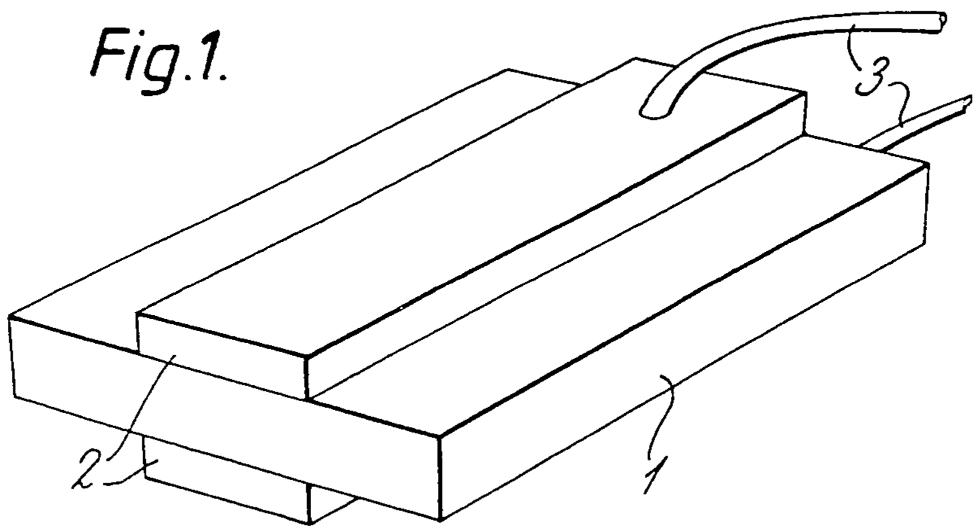


Fig.6.

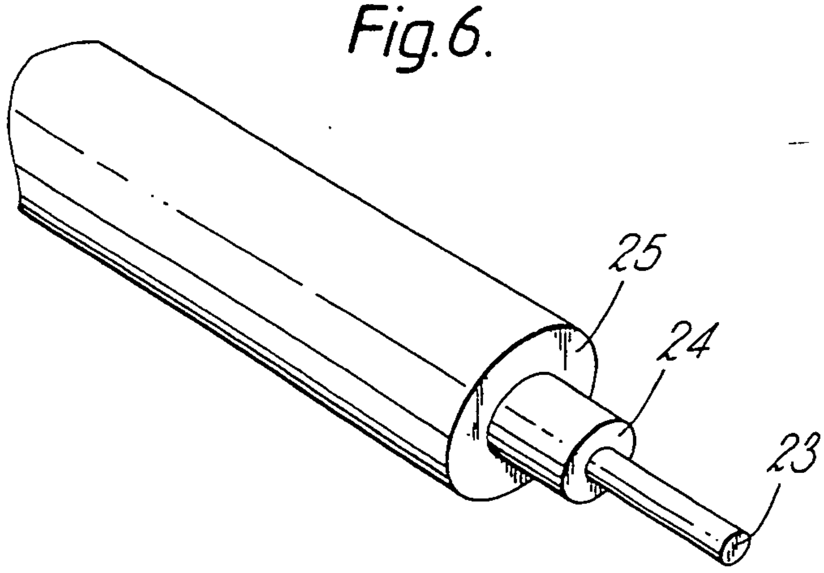
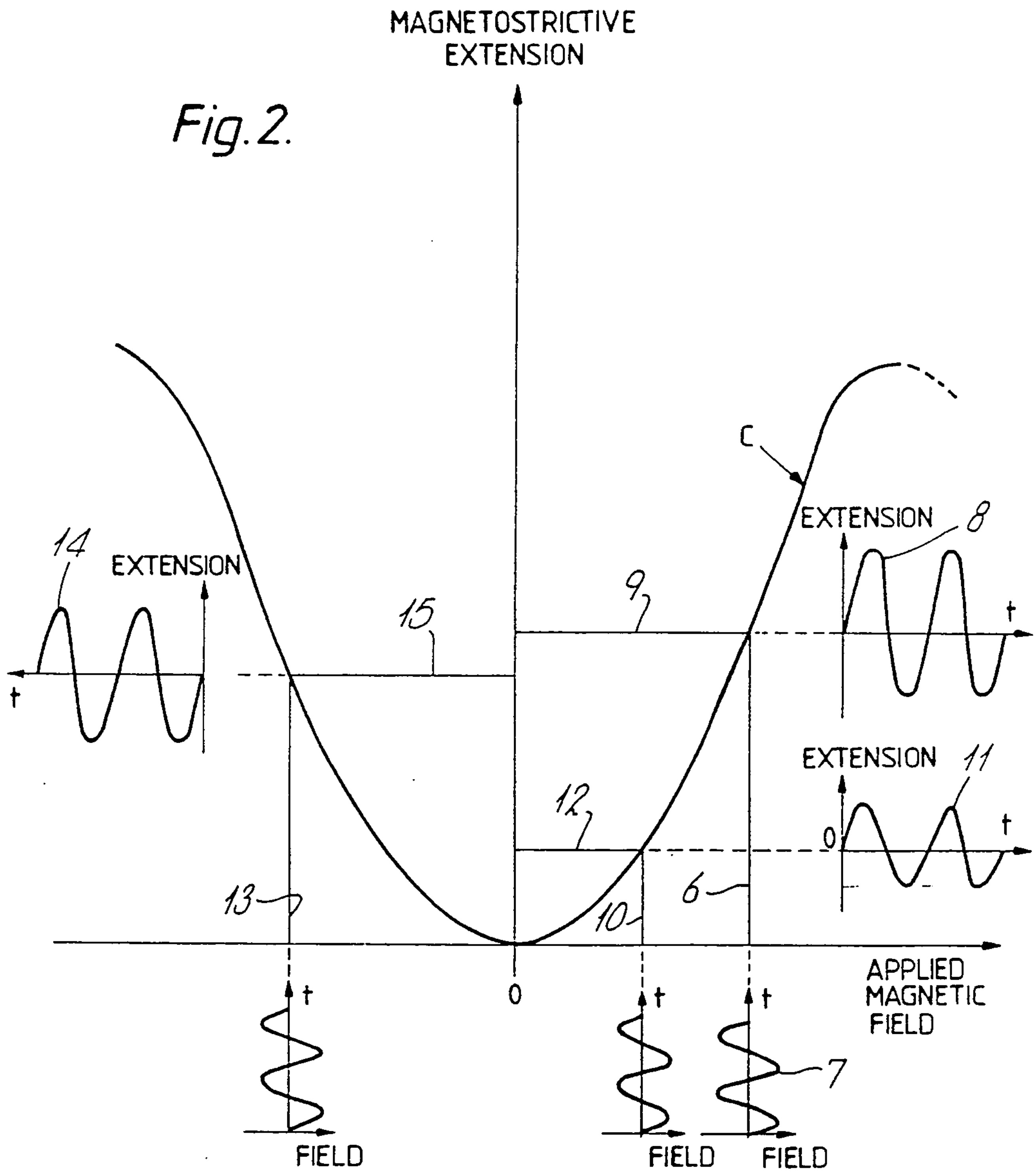


Fig. 2.


MAGNETOSTRICTIVE
EXTENSION
C
EXTENSION
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14
EXTENSION
9
15
t
t
EXTENSION
11
12
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10
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APPLIED
MAGNETIC
FIELD
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7
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Fig.3.

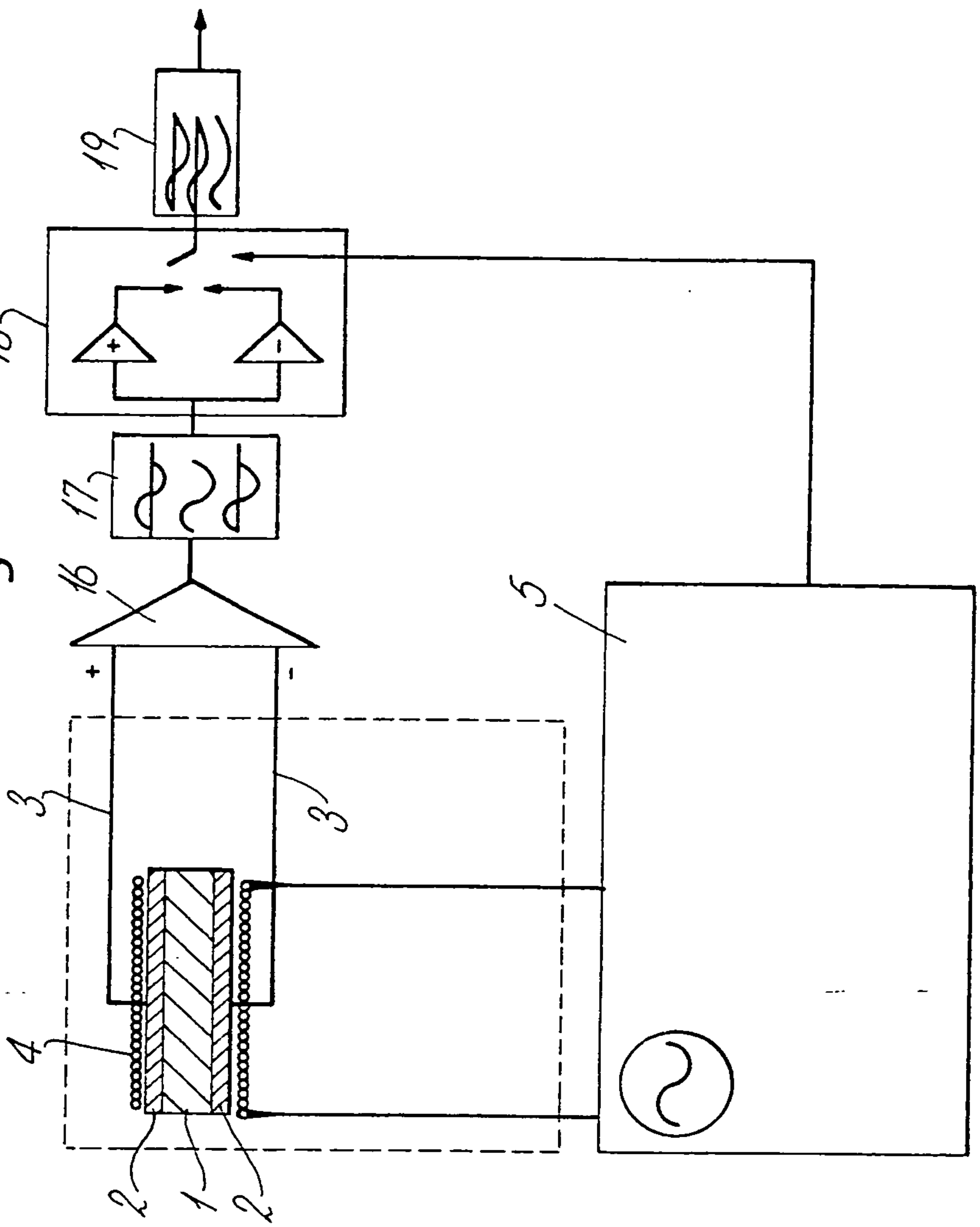
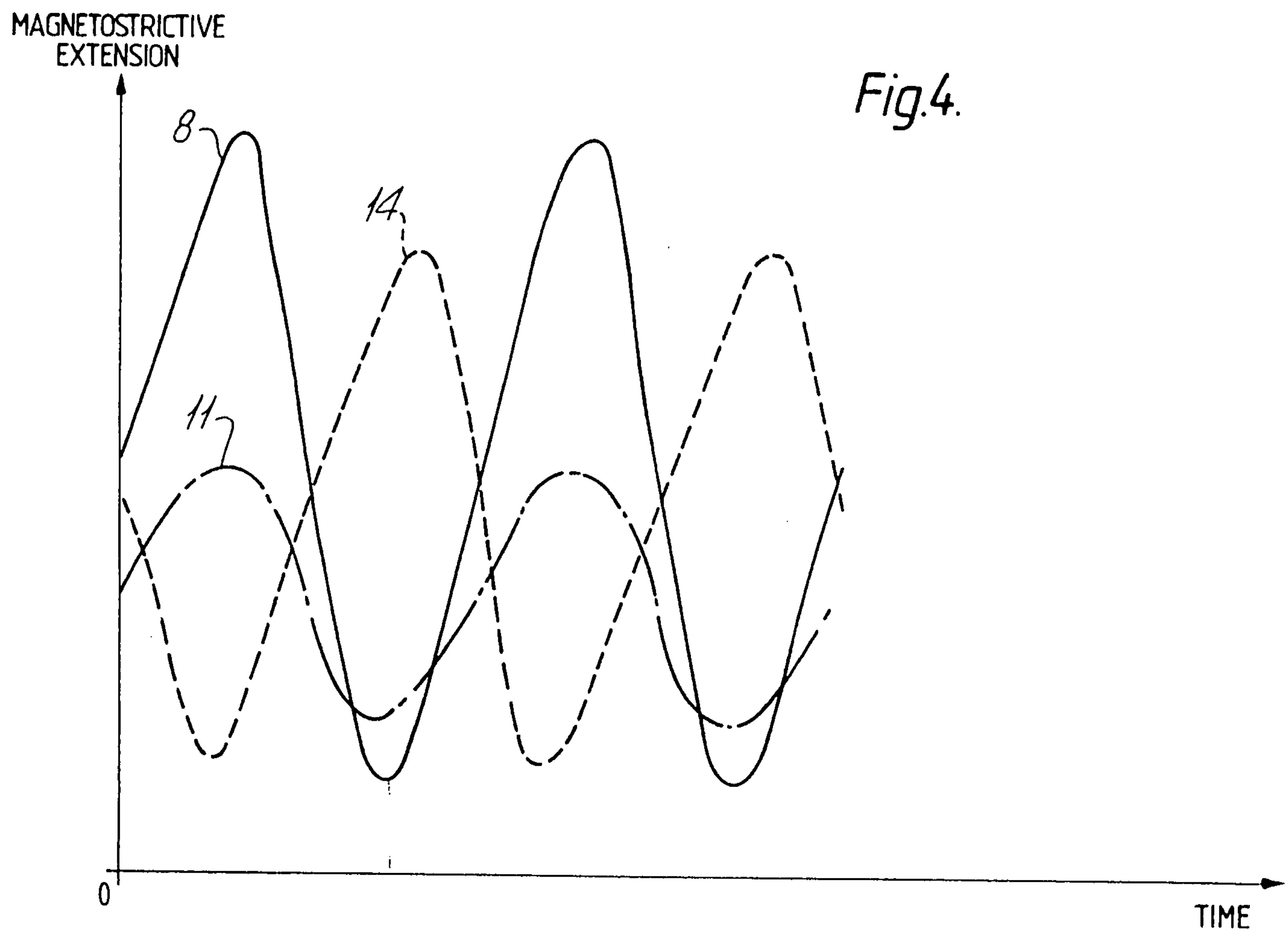


Fig.4.



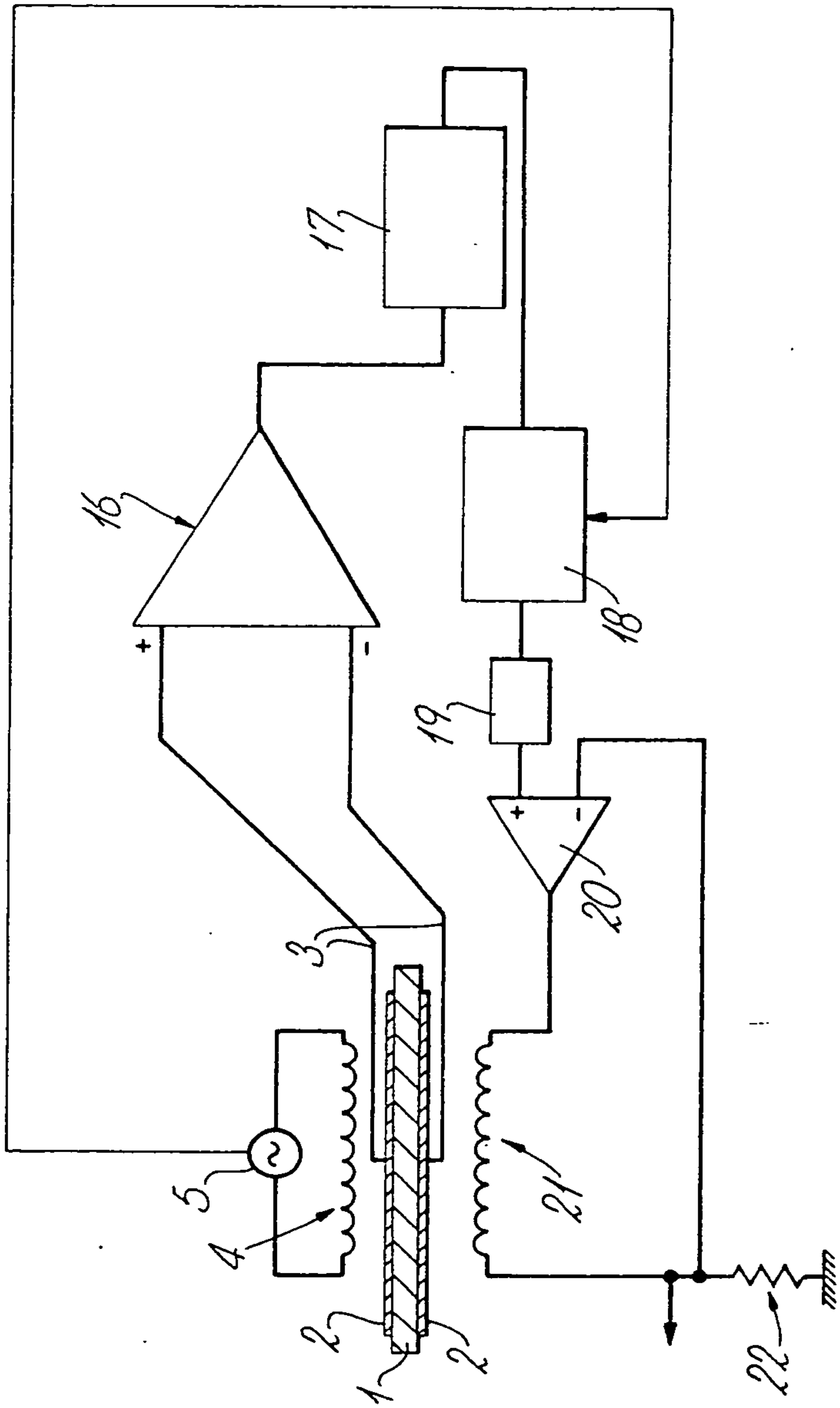


Fig.5.

SPECIFICATION

Magnetic sensor arrangements

This invention relates to magnetic sensor arrangements.

More particularly the invention relates to magnetic sensor arrangements of the kind incorporating a magnetic sensor comprising a magnetostrictive first member having a dimension dependent on the strength of an applied magnetic field, and a piezoelectric second member, secured to the first member, so as to generate a potential difference representative of said dimension of the first member and hence of the magnitude of the applied magnetic field.

In such magnetic sensors build-up of charge on the surfaces of the second member, thermal expansion of the first and second members and electron drift in the second member can create a potential difference in addition to the potential difference indicative of the magnitude of the applied magnetic field and hence result in the sensor being noisy and unstable in operation.

It is an object of the present invention to provide a magnetic sensor arrangement wherein the above disadvantages are overcome.

According to the present invention there is provided a magnetic sensor arrangement comprising a magnetic sensor having a magnetostrictive first member having a dimension dependent on the strength of an applied magnetic field, and a piezoelectric second member secured to said first member so as to generate a potential difference representative of said dimension of said first member, said potential difference constituting the output of the sensor; an electromagnet arranged to apply an alternating magnetic field to said sensor in the direction of the said dimension; and circuit means for detecting the amplitude of the alternating component of the output of said sensor.

Various magnetic sensor arrangements in accordance with the invention will now be described by way of example with reference to the accompanying drawings of which:-

Figure 1 is a perspective view of a first magnetic sensor suitable for use in the arrangements;

Figure 2 is a graph illustrating the operation of the sensor of Figure 1;

Figure 3 is a schematic diagram of a first magnetic sensor arrangement using the sensor of Figure 1;

Figure 4 is a graph showing waveforms occurring in operation of the magnetic sensor arrangement of Figure 3;

Figure 5 is a schematic diagram of a second magnetic sensor arrangement using the sensor of Figure 1; and

Figure 6 is a perspective view of a second magnetic sensor suitable for use in the arrangements.

The magnetic sensors make use of the magnetostrictive and piezoelectric effects. A magnetostrictive material changes its dimensions when placed in a magnetic field and a piezoelectric material builds up a surface charge/voltage when it is subject to compression or tension.

Referring to Figure 1, the first magnetic sensor to be described comprises a rectangular strip of piezoelectric material 1 sandwiched between two rectangular strips of electrically conductive magnetostrictive material 2 having a smaller width than the strip of piezoelectric material 1. The strips 2 are of the same length as the strip 1 and are positioned centrally on opposite main surfaces of the strip 1, with their narrower ends in register with the narrower ends of the strip 1. The piezoelectric material of the strip 1 is polarised so that when subject to compression or tension in a direction parallel to its main faces, the strip 1 will generate a potential difference between its main surfaces. The two strips of magnetostrictive material 2 also serve as electrodes of the sensor and are each provided with a lead 3.

The strip 1 suitably consists of polyvinylidene fluoride (PVDF) and the strips 2 suitably consit of material known by the trade names Metglas 2605C0 (Allied Corporation) or Vitrovac 40-40 (Vacuumschmelze GmBH).

When the magnetic sensor is placed in a magnetic field directed parallel to the planes of the strips 1 and 2, the strips 2 will expand in the direction of the applied field and consequently stretch the strip of piezoelectric material 1 in the same direction. A dc potential difference is consequently generated between the main faces of the strip 1 whose value is representative of the strength of the applied field. The potential difference may thus be applied to a suitable electric circuit via the leads 3 to obtain a measure of the field strength. The relationship between the applied magnetic field and the expansion of the strips is non-linear as shown by the curve C in Figure 2. The same non-linear relationship exists between the generated potential and applied magnetic field, the relationship between the potential and the expansion being approximately linear.

It will be appreciated that the sensitivity of the sensor will depend on the direction of the applied field, the sensor exhibiting maximum sensitivity in the direction of the lengths of the strips 1, 2 and a minimum sensitivity in the direction of the widths of the strips 1, 2. Thus the sensor exhibits a dipole characteristic. In this connection the material of the strip 1 may suitably be itself made directionally sensitive so that it does not respond so readily to change of dimension across its width as along its length. Since a change in length will normally be associated with a change of width of reverse sense, use of such a material will also increase the potential difference generated by a given change in length.

The above described simple dc sensor arrangement suffers from a build-up of charge on the surfaces of the strip 1, thermal expansion of the strips 1, 2 and drift in the piezoelectric strip 1 itself. As a result the sensor is noisy and unstable in operation. These difficulties may be overcome by using the sensor in a circuit in accordance with the invention as shown in Figure 3.

Referring to Figure 3 the circuit includes a solenoid 4 in which the sensor 1, 2, 3 is placed with its

longitudinal axes parallel to the direction of the magnetic field produced by the solenoid 4. The sensor 1, 2, 3 with the solenoid 4 surrounding it, is placed with its longitudinal axis in the direction of the magnetic field to be measured.

In operation an alternating current is supplied to the solenoid 4 from a source 5. In consequence, due to the shape of the curve C, the extension of the strips 2 varies with the alternating field produced by the solenoid 4 by an amount dependent on the value of the field to be measured about a mean value of extension set by the value of the field to be measured. Hence a unidirectional voltage having undulations of an amplitude set by the field to be measured appears between the leads 3 of the sensor. This will be further explained with reference to Figure 2.

If the magnetic field to be measured has a value as indicated by the line 6 in Figure 2 and the alternating magnetic field due to the solenoid 4 has an amplitude indicated by the waveform 7, then the corresponding extension of the strips 2 varies as indicated by the waveform 8 about a mean value indicated by the line 9. Due to the shape of the curve C in Figure 2 the amplitude and phase of the variation of the extension of the strips 2 depends respectively upon the value and direction of the magnetic field to be measured.

Hence for a magnetic field to be measured of a value indicated by the line 10 in Figure 2 of smaller value than the value indicated by the line 6, but the same direction, the corresponding extension of the strips 2 is as indicated by waveform 11 in Figure 2 about a mean value indicated by line 12. For a field to be measured of a value indicated by line 13 in Figure 2 of the opposite direction to the value indicated by lines 6 and 10, the extension of the strips 2 is as indicated by waveform 14 about a mean value indicated by the line 15, the waveform 7 which is opposite to that of waveforms 8 and 11.

The waveforms 8, 11 and 14 are shown in Figure 4 to facilitate comparison.

The voltages produced between the leads 3 are, of course, of corresponding waveform to the extensions of the strips 2.

Referring again to Figure 3, the voltage between the leads 3 is fed via a differential amplifier 16 to a bandpass filter 17. This removes the dc component of the output of the amplifier 16 and hence removes the aforementioned effects of drift and noise in the strips 1. The output of filter 17 will, therefore, comprise a double sideband suppressed carrier version of a carrier of the frequency of the source 5 amplitude modulated by the field to be measured. The output of the filter 17 is fed to a synchronous demodulator 18 wherein its amplitude is detected followed by a low pass filter 19 to provide a dc signal whose value is representative of the value of the magnetic field to be measured.

Referring now to Figure 5, in a modification of the circuit of Figure 3 the output of the filter 19 is supplied to the positive input of a differential dc amplifier 20 whose output is supplied via a coil 21 to load resistor 22. The voltage across the resistor 22 constitutes the output of the circuit and is applied to the negative input of the amplifier 20. The coil 21 is arranged adjacent the sensor 1, 2, 3 so as to apply to the sensor a magnetic field in opposition to the field to be measured. Hence the circuit operates as a dc negative feedback arrangement increasing the dynamic range of magnetic field to be measured to which the sensor will respond. The system linearity is also increased.

It will be understood that whilst the sensor described above by way of example comprises a strip of piezoelectric material sandwiched between two strips of magnetostrictive material, the sensor of an arrangement according to the invention may have many alternative geometric forms.

Referring to Figure 6, one such alternative form of sensor comprises a central electrically conductive member 23 around the outside of which is secured a tubular member 24 of piezoelectric material around the outside of which, in turn, there is secured a tubular member of magnetostrictive material 25. With the piezoelectric member 24 appropriately polarised, the sensor has a maximum sensitivity to an applied magnetic field in the axial direction. This arrangement has the advantage compared with the arrangement of Figure 1 that it is symmetrical in the plane perpendicular to its axis of maximum sensitivity.

In another alternative form, not illustrated, the sensor comprises a circular plate of piezoelectric material sandwiched between two identically sized circular plates of magnetostrictive material. With the piezoelectric plate appropriately polarised the sensor acts as a unidirectional sensor to fields in a direction parallel to the plates.

In a further alternative form, not illustrated, a single planar member of magnetostrictive material is sandwiched between two planar members of piezoelectric material, and metal electrodes are provided on the major surfaces of the piezoelectric members remote from the magnetostrictive member. An output is then derived from between a lead connected to the two electrodes and a lead connected to the magnetostrictive member.

It will further be understood that whilst in the sensors described above the magnetostrictive members are electrically conductive and serve as electrodes, in other sensors the magnetostrictive members may be associated with layers of a suitable metal, such as gold, which serve as electrodes.

CLAIMS

1. A magnetic sensor arrangement comprising: a magnetic sensor having a magnetostrictive first member having a dimension dependent on the strength of an applied magnetic field, and a piezoelectric second member secured to said first member so as to generate a potential difference representative of said dimension of said first member, said potential difference constituting the output of the sensor; an electromagnet arranged to apply an alternating magnetic field to said sensor in the direction of the said dimension; and circuit means for detecting the amplitude of the alternating component of the output of said sensor.

2. An arrangement according to Claim 1 wherein said circuit means also detects the phase of said alternating component.

3. An arrangement according to Claim 1 or Claim 2 wherein said circuit means comprises a synchronous demodulator.

4. An arrangement according to any one of the preceding claims wherein said circuit means includes filter means to remove the dc component in the output of the sensor.

5. An arrangement according to Claim 4 wherein said circuit means includes filter means for smoothing the detected signal.

6. An arrangement according to any one of the preceding claims further including an electromagnet responsive to the output of said circuit means to apply a dc magnetic field to said sensor having a magnitude dependent on the first-mentioned applied magnetic field but in opposition thereto, thereby to provide a negative feedback arrangement.

7. An arrangement according to any one of the preceding claims wherein said first member is secured to a first surface of said second member and said output is derived from between said first surface and a second surface of said second member opposite said first surface.

8. An arrangement according to Claim 7 wherein a magnetostrictive third member having a dimension dependent on the strength of said magnetic field is secured to said second surface.

9. An arrangement according to any one of the preceding claims wherein said members are of planar form and are secured to one another in parallel relationship.

10. An arrangement according to any one of Claims 1 to 8 wherein said members are of cylindrical form and are secured to one another in co-axial relationship.

11. An arrangement according to any one of the preceding claims wherein the or said magnetrostrictive member consists of an electrically conductive material and serves as an electrode for sensing said potential difference.

12. A magnetic sensor arrangement substantially as hereinbefore described with reference to Figure 3 or Figure 5 of the accompanying drawings.

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